

AN INEXPENSIVE FORCE PLATFORM FOR USE WITH SMALL ANIMALS: DESIGN AND APPLICATION

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A force platform was designed and manufactured to meet the following criteria. 1. be inexpensive and able to be constructed from readily available components. 2. be suitable for use with animals of less than 1 kg and able to provide an indication of the direction and timing of the forces produced by a lizard during locomotion. 3. be small enough to record forces from a pair of ipsilateral feet only, but large enough to allow a reasonable chance for a running lizard to place its feet on the platform.

A force analysis of Bearded Dragons (*Amphibolurus barbatus*) and Water Dragons (*Physignathus lesueurii*) indicated that unlike the more erect mammals, the legs of lizards apply no forward force to the ground during the limb cycle. Instead of the acceleration/deceleration cycle that occurs in the limbs of erect mammals, the lizards apparently apply a 'rotational' force that simply alters the angular momentum of the limb. These findings are discussed. □ *Lizards, locomotion, force platform.*

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The locomotor performance of animals can be investigated in a number of different ways: trackway analysis, for example, can provide estimates of speed, stride length, animal size etc. even for animals that have long been extinct (Thulborn, 1982; Thulborn and Wade, 1984); anatomical studies can elucidate certain locomotor constraints (e.g. Russell and Rowcastle, 1979); and kinematic analysis has been used to provide comparative data useful in understanding locomotor abnormalities (Parker and Bronks, 1980). However, none of these methods can provide more than an estimate of the way in which forces are transmitted to the ground during locomotion; to measure these ground reaction forces, a force platform is required. Unfortunately, force platforms are not always readily available, are often complicated, sometimes not completely suitable and usually extremely expensive. In this paper I describe a force platform that was used as part of a larger study of the locomotion of two species of agamid lizard. The platform is cheap, simple to construct and suitable for use with small animals.

THE FORCE PLATFORM

DESIGN CRITERIA

To produce an inexpensive force platform that could be constructed from readily available components, was suitable for animals less than 1 kg,

and would provide an indication of the direction and timing of the typical forces produced during the locomotion of the lizards used in this study. The platform was to be small enough to record forces from a pair of ipsilateral feet only, but big enough to allow a reasonable chance for a running lizard to place its feet on the platform.

TRANSDUCER ELEMENTS

The most expensive components of a force platform are the transducer elements used to convert variations in the applied forces into signals that can be recorded and analysed. In the system described here, inexpensive, commercially-available crystal microphone elements were modified (Fig. 1 and see below) to act as force transducers. The output from these crystal elements varies with the rate of change of the force (i.e. the first derivative of the force, Fig. 2) thereby making an estimation of the actual value of applied forces an integrating process (either electrical or mathematical). However, as the primary purpose of the force platform was to provide an indication of the direction and timing of the forces applied to the ground by a moving lizard, actual values of the forces were not required and integration of the crystal output was considered unnecessary.

CONSTRUCTION (Fig. 3)

The surface plate for the force platform was

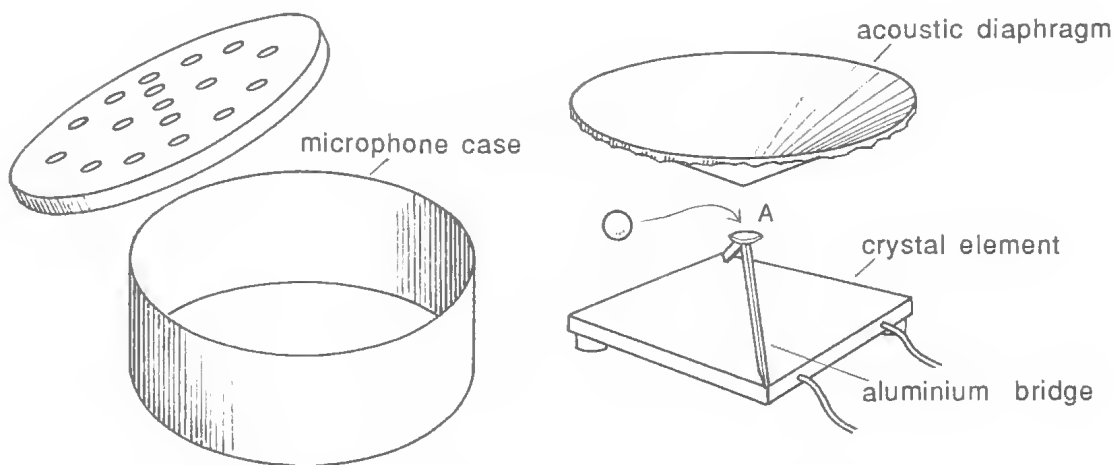


FIG. 1. Exploded view of the crystal microphone element used to provide the force transducers. A: shows the position of attachment of the glass bead.

provided by a piece of aluminium plate 10cm square and 3mm thick. An aluminium cube 25mm to a side was cemented to the centre of the plate and a transducer element was attached to each of the five remaining surfaces of the cube. The transducer element, when removed from the

microphone case and acoustic diaphragm, consisted of a piezo-electric crystal wafer with two small rubber 'feet' mounted on diagonally opposite corners of one side. On the other side an aluminium bridge spanned the two remaining corners. Before fitting the transducer elements to

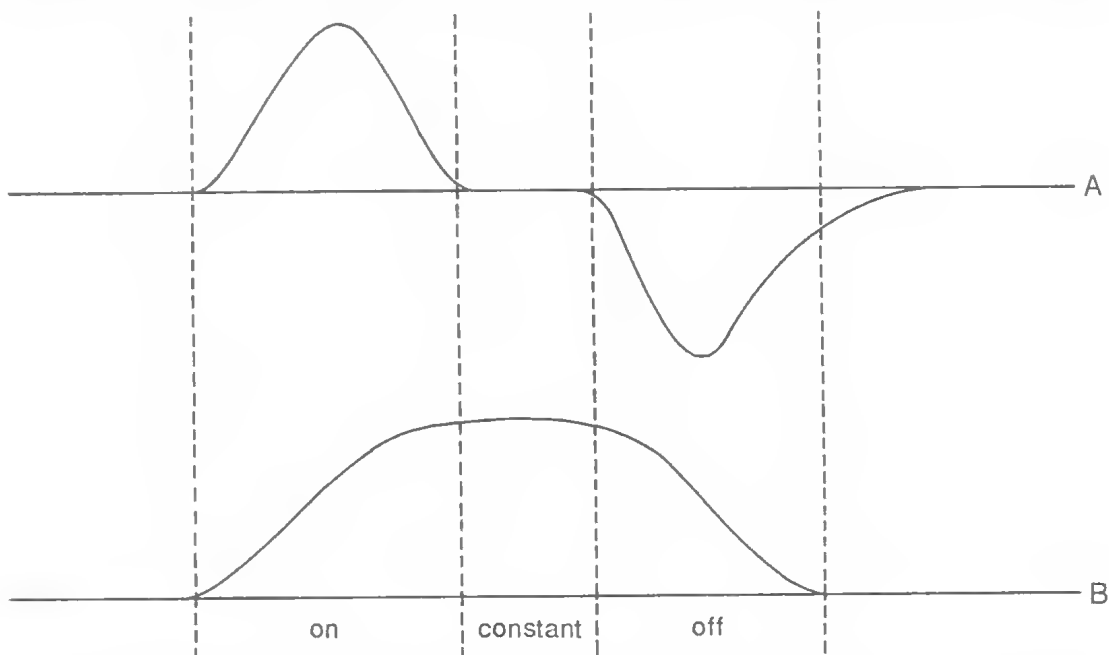


FIG. 2. Force diagrams: Transducer output, the first derivative of the force (A), compared with the actual force (B) its integral.

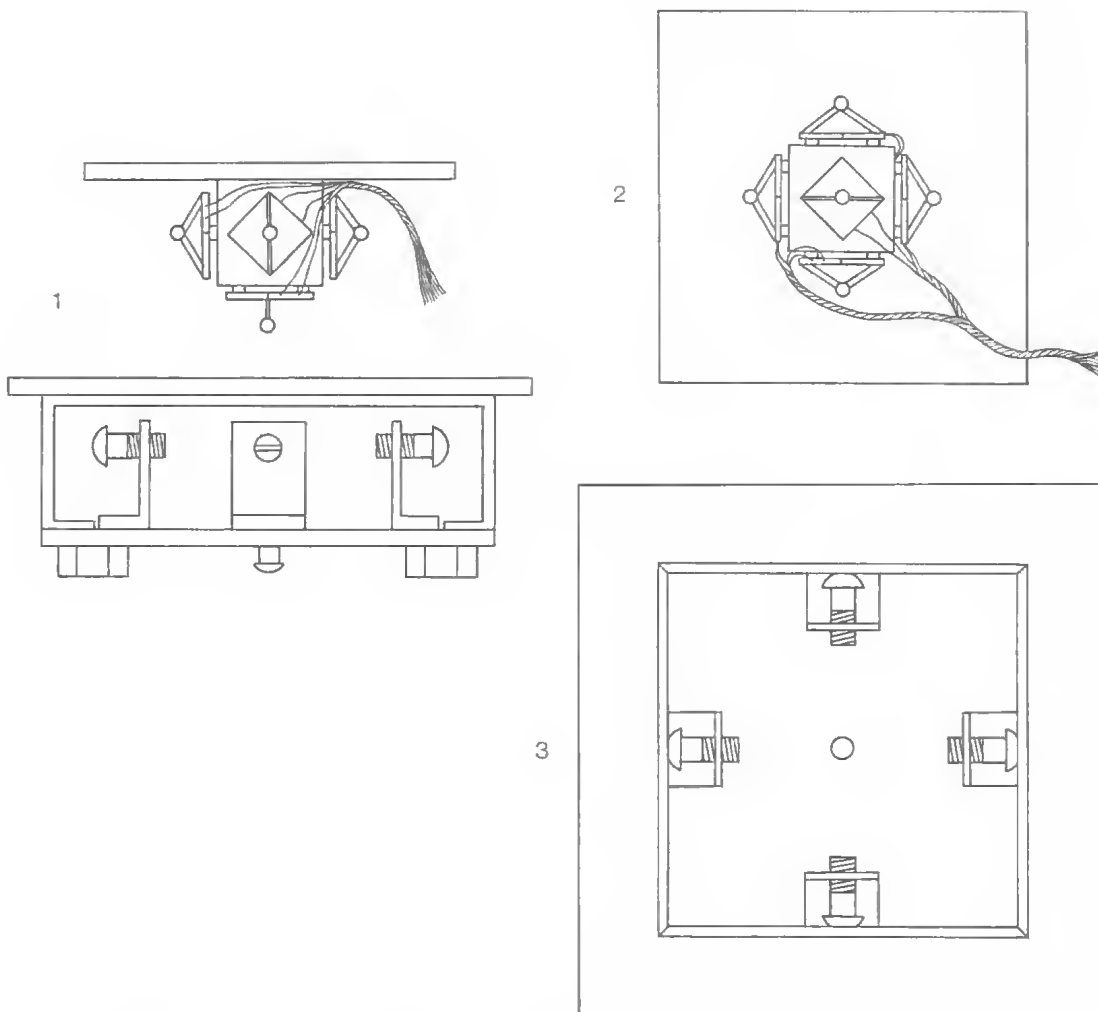


FIG. 3. Exploded view of force platform. 1: Lateral view of plate and base; 2: Ventral view of plate (note the arrangement of transducer elements); 3: Dorsal view of base.

the surface plate, a 3mm diameter glass bead was cemented at the apex of the bridge of each element. The surface plate was recessed into and supported by the body of the force platform which was also made from aluminium. Initially the surface plate was separated from the body of the force platform by a thin layer of low density foam but this arrangement was found to be overly sensitive and a more rigid, silicone jointing compound (silastic) was later used. The silastic effectively damped the plate and the amount used was varied, in conjunction with the degree of signal amplification, to suit the size of the lizard that was running over the platform during any particular set of trials. Five fine-thread brass screws were mounted in the body of the platform

in such a way that they could be screwed up until just touching the glass bead of the transducer element. To reduce friction, and hence 'crosstalk' between the transducers, the ends of the screws were machined and polished and coated with teflon grease. Coarse grade sandpaper was glued to the top of the force plate which was recessed into the floor on one side of the runway. Electrical leads from each of the transducers were connected to a Grass 79D four-pen chart-recorder and the force platform was calibrated in situ before and after a set of trials for each lizard. As there were five transducers, but only four recorder pens, the output from lateral and medial transducers was duplexed to a single chart-recorder pen so that a laterally

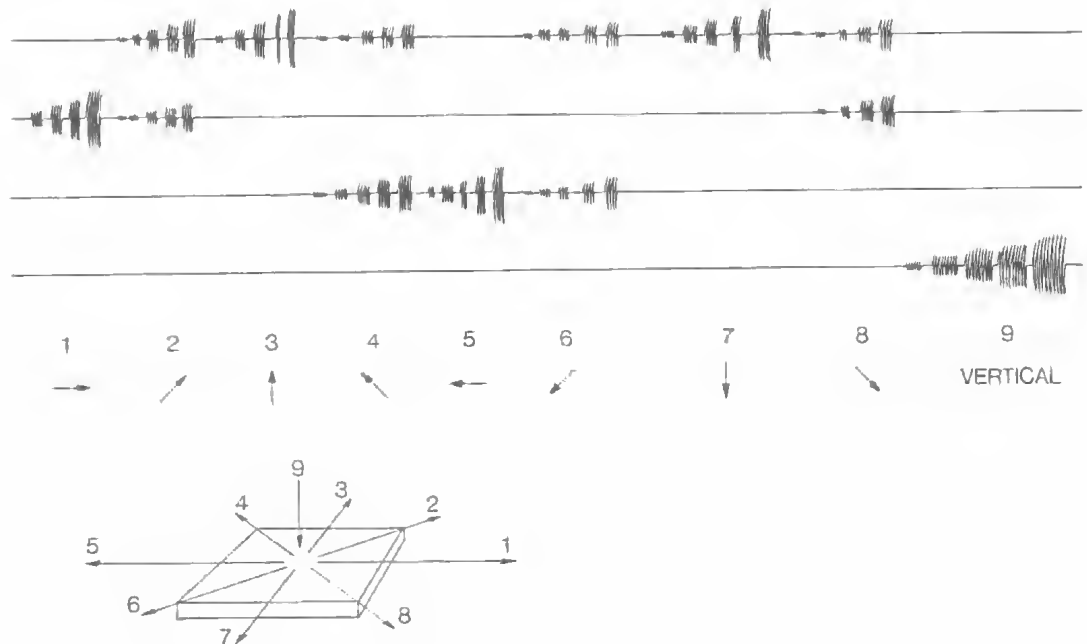


FIG. 4. Calibration of the force platform. A,B,C,: Horizontal transducer outputs; D: Vertical transducer outputs. 1-9 directions of application of force to the plate.

directed force resulted in an initial pen displacement in one direction and a medially directed force in the other.

CALIBRATION

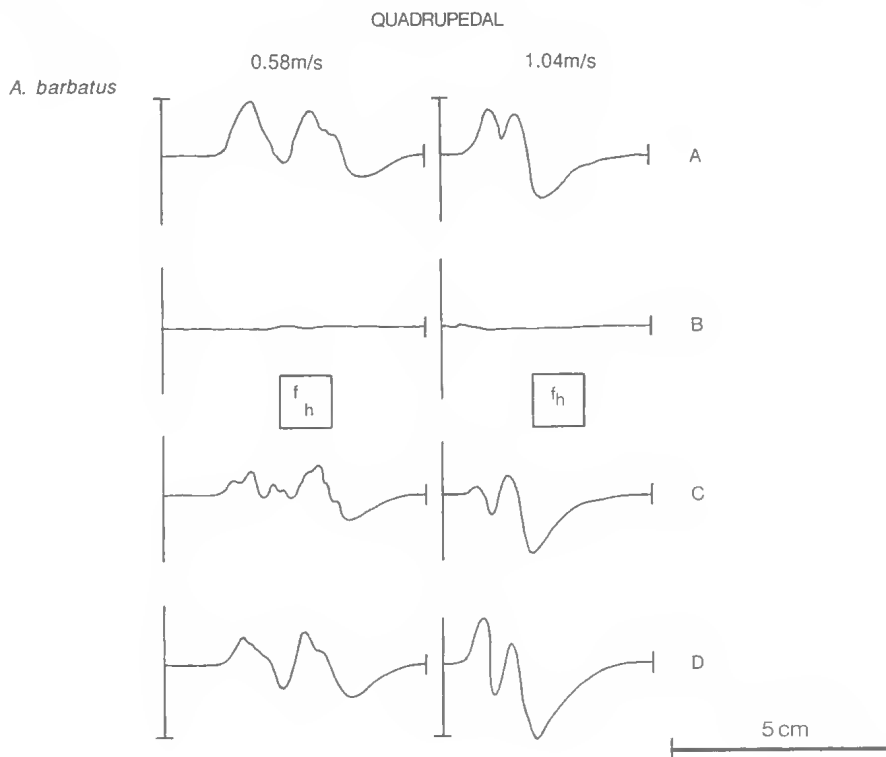
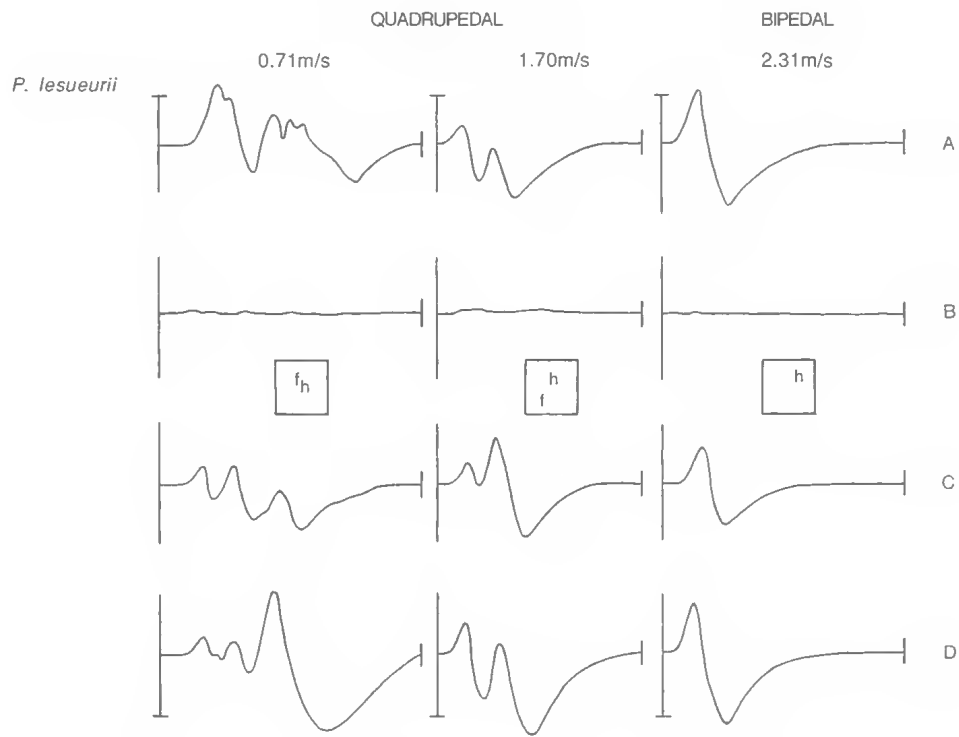
Fig. 4 is an example of the calibration record obtained from the force platform before and after each set of trials for a particular lizard. As shown, repetitive sequences of force were applied at 45° angles through 360° of a horizontal plane and vertically downwards. Force increments in each series were 50g and the forces applied ranged from 50g to 250g. As nearly as could be determined: 1. each of the transducers reacted instantaneously to the application a force; 2. each transducer reacted if a component of the applied force acted on it, and; 3. 'crosstalk' from transducers that had no component of the force acting on them was minimal.

PERFORMANCE

Hegland (1981, p.333) has listed eight at-

tributes of an ideal force platform. It should (1) be able to resolve the vertical, forward and lateral components of the force; (2) have low "crosstalk" between the measured components of the force, (3) have sufficient sensitivity and resolution for the subject of interest; (4) have a linear response; (5) have a response independent of where on the plate surface the force is exerted; (6) have a high natural frequency of oscillation; (7) have sufficient safety margin to protect both the plate and subject from damage due to failure; and (8) be simple and inexpensive.' The force platform described here meets most of these requirements but is perhaps questionable in three of them; (a) Linearity of response (no.4) - this was not critically assessed but is, to a large extent, dependent on the transducer elements. Improvement in this area would require better, hence more expensive, crystal elements, which is not necessary under the stated design criteria. (b) Response independent of position on the plate (no.5) - the response of this plate was found to vary slightly the further a foot was placed from

FIG. 5. Derivatives of the components of the ground reaction forces: (As applied by the lizard). A: Lateral force component; B: Forward component; C: Backward component; D: Vertical (downward) component. f and h are the points at which fore and hind feet respectively were placed on the force platform.



the centre of the plate. This factor was controlled during the study by only using records where the foot or feet had been placed centrally on the plate. (c) Frequency of oscillation (no.6) - the frequency of oscillation is a function of the jointing compound used to damp the plate and can be controlled only marginally. However, in terms of the design criteria of the platform, this is relatively unimportant. In general, the force platform described here was found to fulfill the design criteria adequately and be capable of providing records of the direction and timing of the components of the ground reaction forces produced by a running lizard.

METHODS

Two Bearded Dragons (*Amphibolurus barbatus*: snout-vent lengths of 180mm and 239mm and weights of 148.5g and 403.5g respectively), and two Water Dragons (*Physignathus lesueurii*: snout-vent lengths of 172mm and 212mm and weights of 180.9g and 337.5g respectively) were used in the trials. Each lizard was encouraged to run in either direction along the runway as often as was necessary to produce acceptable force records for right and left ipsilateral feet. Trials were extended to obtain force records for the hind feet of Water Dragons moving bipedally.

RESULTS

Fig.5 shows typical records of the forces exerted by both species of lizard during quadrupedal locomotion and by Water Dragons during bipedal locomotion. Force records for left and right feet were essentially the same and only records from right feet are presented here for comparison. All records exhibit three distinct components of the force: a lateral component, a backward component and a vertical component. None of the records gave any indication that there was a forward component to the force exerted by a lizard during locomotion. Two major peaks are evident in each of the force components for all animals during quadrupedal locomotion and these correspond to the rates of force application by a front foot followed by a hind foot. At lower speeds, minor peaks can be seen within the major peaks for each foot, but as speed increases the minor peaks in the profiles become less obvious. All three components of the force for each foot were initiated at the same time and, at lower speeds, have approximately the same rate and duration of application. At

higher speeds, however, the rate of application of the backward force, by a front foot, was less than that for the vertical and lateral components of the same foot. As is to be expected, the duration of the power stroke at higher speeds was considerably less than it was for lower speeds. Force records for bipedal locomotion are similar to records for hind feet during fast quadrupedal locomotion - each component of the force consisting of only one major peak with a relatively smooth profile. The initiation and duration of all three force components was the same but the maximum rate of application of the backward component was consistently less than that for the other two components. The duration of the power stroke during bipedal locomotion varied only slightly with speed and was similar to the duration of the power stroke during fast quadrupedal locomotion.

DISCUSSION

Because the force platform had to be preloaded to different degrees during each trial, the force records presented in Figure 5 can not be used to provide estimates of the absolute magnitudes of the forces applied to the plate by a running lizard. However, the components of the force can be compared within each trial to provide an indication of their relative importance. For convenience, forces are discussed here in terms of 'as applied by the lizard'; for example, a backward force means the force, or force component, applied by the lizard in a caudal direction resulting in the animal moving forwards.

Perhaps the most surprising result of the force analysis in this investigation is the lack of any indication of a forward component to the horizontal force exerted on the ground. The alternation of forward and backward forces during a locomotor cycle is responsible for the fluctuation in kinetic energy and consequently for a large part of the energy cost of locomotion. Yet Alexander (1977) showed mathematically that for a range of bipedal and quadrupedal animals it is energetically more efficient to incorporate both backward and forward components of force into the locomotor cycle. It would seem from Alexander's (1977) formulation that the locomotion of lizards is energetically inefficient and yet Bakker's (1972) investigations give evidence to the contrary. Although a mathematical analysis of the forces applied during lizard locomotion is beyond the scope of this investigation there may be a simple solution to this apparent conflict.

Alexander's model of applied forces relies (as he points out) on the height at the hip being greater than half the step length (step length = distance the animal moves while a foot is on the ground), which it apparently is for most animals (Alexander, 1977). Hip height in a lizard, however is less than 30% of total step length.

In fact, the way lizards apply force to the ground may even be the reason for their slightly greater locomotor efficiency (Bakker, 1972) than mammals of a similar size. Although Jenkins (1971) has shown that significant femoral abduction occurs in many species of small mammals, the movement of their limbs is still essentially forwards and backwards: energy must be expended to accelerate and decelerate the limb in both directions. By comparison, the movement of the limb of a lizard during locomotion is essentially rotatory: energy need be applied only to change its angular momentum. Although this may be an oversimplification, work by Fedak et al. (1982) has shown that the energetic cost of the changes in the potential energy of the limbs of some bipeds and quadrupeds during locomotion was not as high as expected because the essentially parasagittal movement of the limb in these animals also included a slight rotatory component. Further investigation in this area should prove instructive.

ACKNOWLEDGEMENTS

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TROPIDONOTUS MAIRII VS BUFO MARINUS: — *Bufo marinus* was released in sugar-growing districts of eastern Queensland in 1935–6 and now occurs widely in that State and in northeast New South Wales. It is a highly toxic species (Meyer and Linde, 1971, p.522). The bulk of the venom is contained in the parotid glands. Venom is also secreted by smaller glands that cover the whole animal and toxins have been identified in other parts of the body, e.g. blood and ovaries (Meyer and Linde, 1971). The eggs also contain toxins (Licht, 1967) and, although there are no data on toxicity of the larvae, it does not seem unreasonable to assume they are also toxic.

Several native vertebrates can utilise *B. marinus* as a food source by eating eggs, larvae, newly metamorphosed young (e.g. Jungle Perch, *Kuhlia rupestris*; Snapping Turtle, *Elseyia latisternum*; Green Tree Snake, *Dendrelaphis punctulatus*; Common Keelback, *Tropidonotus mairii*) and selected body organs (e.g. Crow, *Corvus* sp.; Swamp Hen, *Porphyrio porphyrio*; White Ibis, *Threskiornis mollucca*; Water Rat, *Hydromys chrysogaster*); or by 'washing' adults prior to ingestion (captive Estuarine Crocodiles, *Crocodylus porosus* have been observed washing *B. marinus* by shaking them vigorously in water for several minutes prior to successful ingestion) (Covacevich and Archer, 1975; Hamley and Georges, 1985; G. Ingram, pers. obs.).

Australian frog-eating snakes are known to be particularly susceptible to the toxin of *B. marinus* with one exception. This species the Common Keelback Snake (*Tropidonotus mairii*) has been regarded as the most successful and only regular native predator of *B. marinus*. It is known to consume large numbers of eggs, larvae, and newly metamorphosed young (Lyon, 1973; Covacevich and Archer, 1975; C. Tanner pers. comm.). *T. mairii*, a colubrid snake (subfamily Natricinae), is closely related to other natricine species occurring in North and South America, Asia and Europe (Malnate, 1960) where *Bufo* spp. also occur naturally. Its apparent high tolerance of *Bufo marinus* venom was attributed to the long evolutionary association of natricines and bufonids in these areas.

In December, 1976 a dead specimen of *Tropidonotus mairii* (total length 85cm) with a young adult *Bufo marinus* (head width 2.5 cm), one third ingested from the vent (rather than the head as is usual with snakes), was found in the dry

bed of Richter's Creek, 10km north of Cairns, NEQ (Queensland Museum registration no. J 28417). There were no marks on the snake to suggest death from an encounter with a possible predator, and the toad is no larger than other frogs or small mammals commonly consumed by snakes of comparable size. Death from toad toxin is the only apparent explanation.

The discovery of this single known unsuccessful encounter between *T. mairii* and *B. marinus* is not conclusive evidence that larger *B. marinus* are invariably toxic to *T. mairii*, but this species is apparently more susceptible to *B. marinus* toxins than was supposed, particularly because in the case reported here, the snake had begun to ingest the toad from the rear, thus avoiding toxin concentrations in the parotid glands immediately behind the head.

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